

# **EXHIBIT H**



# Camera Lenses

## From Box Camera to Digital

Gregory Hallock Smith



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# Contents

<b>Part A Concepts and Techniques</b>	<b>1</b>
<b>1 Introduction</b>	<b>3</b>
1.1 Light .....	3
1.2 Recording Light .....	4
1.3 The Beginnings of Photographic Optics .....	5
1.4 Photography and Imaging .....	6
1.5 Cameras, Lenses, and Theory .....	6
<b>2 Films and Emulsions</b>	<b>9</b>
2.1 The Daguerreotype .....	9
2.2 The Calotype .....	9
2.3 The Collodion Wet-Plate .....	10
2.4 The Gelatin Dry-Plate .....	10
2.5 How a Photographic Emulsion Works .....	11
2.6 Spectral Sensitivity .....	12
2.7 Color Photography and Films .....	13
2.7.1 Autochrome .....	13
2.7.2 Technicolor .....	14
2.7.3 Kodachrome .....	15
2.7.4 Agfachrome and Ektachrome .....	15
2.8 Standard Film Format Sizes .....	15
<b>3 Electronic Image Sensors</b>	<b>17</b>
3.1 The Charge-Coupled Device .....	17
3.2 Types of CCDs .....	18
3.2.1 Full-frame .....	19
3.2.2 Frame-transfer .....	19
3.2.3 Interline-transfer .....	20
3.3 CMOS Image Sensors .....	20
3.4 Impactron CCD Sensors .....	21
3.5 Color Electronic Cameras .....	22

3.6 Coding Color in Video and Digital .....	23
3.7 Standard CCD/CMOS Format Sizes .....	24
3.8 Applications .....	25
<b>4 Limiting Resolution of Image Sensors</b>	<b>27</b>
4.1 Film Limiting Resolution .....	27
4.2 CCD/CMOS Limiting Resolution .....	28
4.3 Total Numbers of Pixels .....	30
<b>5 Silver and Silicon</b>	<b>31</b>
5.1 Film versus Electronic Image Sensors .....	31
5.1.1 Practical picture-taking .....	31
5.1.2 Machine vision .....	32
5.1.3 Grain, pixelation, and resolution .....	32
5.1.4 Quantum efficiency and speed .....	32
5.1.5 Reciprocity, fog, and dark current .....	33
5.1.6 Maximum detector size .....	33
5.1.7 Spectral response .....	34
5.1.8 Photometric response .....	34
5.1.9 Calibration .....	34
5.1.10 Output form .....	35
5.1.11 Image permanence .....	35
5.2 Matching Sensors to the Application .....	35
5.2.1 Snapshots .....	35
5.2.2 Advanced amateur cameras .....	36
5.2.3 News, sports, and action .....	36
5.2.4 Movie films .....	36
5.2.5 Portraits .....	37
5.2.6 Glossy magazines .....	37
5.2.7 Advertising photography .....	37
5.2.8 Museum conservation/documentation .....	37
5.2.9 Artistic photography .....	37
5.2.10 Scientific photography .....	38
5.3 Trends .....	38
<b>6 Cameras as Systems</b>	<b>39</b>
6.1 Defining System Parameters .....	39
6.2 Effect of Object Distance .....	40
6.3 Curved Field versus Flat Field .....	41
6.4 Fast and Slow Lenses and Detectors .....	41
6.5 Antireflection Coatings .....	41
6.6 Single-Lens-Reflex versus Rangefinder-Viewfinder .....	42
6.7 Zoom Lenses .....	43
<b>7 Basic Geometrical Optics</b>	<b>45</b>
7.1 Geometrical and Physical Optics .....	45
7.2 Lenses and Mirrors .....	45

7.3 Objects and Images .....	46
7.3.1 Real and virtual objects and images .....	47
7.4 Optical Axis .....	47
7.5 Stops .....	47
7.6 Vignetting .....	48
7.7 Marginal and Chief Rays .....	48
7.8 Pupils .....	49
7.9 Focal Length .....	50
7.10 Focal Ratio .....	50
7.11 Surface Shapes .....	51
7.12 Paraxial Optics and First-Order Properties .....	52
<b>8 Aberrations</b>	<b>53</b>
8.1 The Major Ray Aberrations .....	53
8.1.1 Longitudinal chromatic aberration .....	53
8.1.2 Lateral chromatic aberration .....	54
8.1.3 Spherical aberration .....	54
8.1.4 Coma .....	54
8.1.5 Astigmatism and field curvature .....	54
8.1.6 Distortion .....	56
8.1.7 Other Aberrations .....	56
8.2 Petzval Curvature .....	58
8.3 Effective Focal Length and Back Focal Length .....	59
8.4 Aberrations in Terms of BFL and EFL .....	60
8.5 Blur Size Dependences .....	61
<b>9 Basic Physical Optics</b>	<b>63</b>
9.1 Wavefronts and Optical Path Differences .....	63
9.2 Diffraction .....	64
9.3 The Airy Disk .....	65
9.4 Diffraction Plus Aberrations .....	66
<b>10 Designing Camera Lenses</b>	<b>69</b>
10.1 The Design Process .....	69
10.2 Optimizing with Rays versus OPDs .....	70
10.3 Aspheric Lens Surfaces .....	71
10.4 The Symmetry Principle .....	72
10.5 Scaling the System .....	73
10.6 Optical Prescriptions .....	74
10.7 Optical Patents .....	74
<b>11 How to Handle Vignetting</b>	<b>77</b>
11.1 Delete Vignetted Rays .....	78
11.2 Vignetting Factors .....	78
11.3 User-Defined Constraints .....	79
<b>12 Optical Glass</b>	<b>81</b>
12.1 Refractive Index .....	81

Contents		
12.2	Dispersion .....	82
12.3	Partial Dispersion .....	82
12.4	Color Correction .....	84
12.4.1	Singlets .....	84
12.4.2	Mirrors .....	84
12.4.3	Achromats .....	84
12.4.4	Apochromats .....	85
12.5	Glass Manufacturers .....	85
12.6	Environmentally Friendly Glasses .....	86
<b>13</b>	<b>Evaluating Camera Lens Performance</b>	<b>87</b>
13.1	Layout .....	87
13.2	Spot Diagrams .....	89
13.3	Ray Fan Plots .....	91
13.4	Optical Path Differences .....	93
13.5	Astigmatism and Field Curvature .....	93
13.6	Distortion .....	93
13.7	Relative Image Illumination .....	95
13.8	Point Spread Function .....	96
13.9	The Strehl Ratio .....	98
13.10	Encircled and Ensquared Energy .....	99
13.11	Ghost-Image Analysis .....	100
13.12	Tolerance Analysis .....	100
13.13	Further Considerations .....	100
<b>14</b>	<b>Spatial Frequency Response of Lenses</b>	<b>101</b>
14.1	Spatial Frequencies .....	101
14.2	Modulation Transfer Function .....	102
14.3	Spurious Resolution .....	105
14.4	Aliasing .....	105
<b>15</b>	<b>How Camera Lenses Perform Stopped Down</b>	<b>107</b>
15.1	The $f/2$ Double-Gauss .....	107
15.2	Other Examples .....	113
15.3	Vibrations and Tripods .....	114
<b>16</b>	<b>Optics-Limited or Detector-Limited</b>	<b>115</b>
16.1	Sharpest Images in Camera Lenses .....	115
16.2	Sampling the Point Spread Function .....	115
16.3	Small-Format Digital Cameras .....	116
16.4	An Example .....	117
16.5	35 mm and 645 Film and Digital Cameras .....	117
16.5.1	Film .....	117
16.5.2	Digital .....	118
16.6	Large-Format Film Cameras .....	118
16.7	Television .....	119

Contents		
<b>17</b>	<b>Choosing Your Camera</b>	<b>121</b>
17.1	Film Cameras .....	121
17.2	Electronic Cameras .....	122
17.3	Cameras of the Future .....	123
<b>Part B Lenses for Large-Format 4 × 5 Film Cameras</b>		<b>125</b>
<b>18</b>	<b>Pre-Anastigmatic Early Lenses</b>	<b>127</b>
18.1	Singlet Landscape Lens .....	128
18.2	Achromatic Landscape Lenses .....	131
18.3	Petzval Portrait Lens .....	134
18.4	Rapid Rectilinear Lens .....	136
<b>19</b>	<b>Symmetrical Anastigmats</b>	<b>139</b>
19.1	Dagor .....	140
19.2	Reversed Dagor .....	143
19.3	Orthostigmat .....	143
19.4	Celor .....	143
<b>20</b>	<b>Higher Performance and Modern Anastigmats</b>	<b>149</b>
20.1	Cooke Triplet .....	149
20.2	Tessar .....	152
20.3	Heliar and Pentac .....	154
20.4	Planar .....	154
20.5	Plasmat .....	158
<b>21</b>	<b>Wide-Angle Lenses</b>	<b>163</b>
21.1	Hypergon .....	163
21.2	Topogon .....	166
21.3	Biogon .....	169
<b>Part C Lenses for Small-Format 35 mm Film and Digital Cameras</b>		<b>173</b>
<b>22</b>	<b>Moderate-Speed Standard Lenses</b>	<b>175</b>
22.1	Cooke Triplet, $f/3.5$ .....	177
22.2	Tessar, $f/3.5$ .....	179
22.3	Tessar, $f/2.8$ .....	182
<b>23</b>	<b>High-Speed Standard Lenses</b>	<b>183</b>
23.1	Double-Gauss, $f/2.0$ .....	184
23.2	Sonnar, $f/2.0$ .....	186
23.3	Double-Gauss, $f/1.4$ .....	188
<b>24</b>	<b>Wide-Angle Lenses</b>	<b>191</b>
24.1	Double-Gauss, 35 mm, $f/2.8$ .....	191
24.2	Biogon, 21 mm, $f/3.5$ .....	193
24.3	Hologon, 15 mm, $f/8.0$ .....	195

24.4	Retrofocus Lenses, 21 mm, $f/3.5$ . . . . .	198
24.4.1	Negative-in-front . . . . .	199
24.4.2	Positive-in-front . . . . .	199
24.5	Full-Frame Fisheye, 14 mm, $f/2.8$ . . . . .	202
24.5.1	Elliptical distortion . . . . .	203
<b>25</b>	<b>Tele Lenses</b>	<b>207</b>
25.1	Double-Gauss, 105 mm, $f/2.8$ . . . . .	207
25.2	Sonnar, 105 mm, $f/2.8$ . . . . .	209
25.3	True Telephoto, 300 mm, $f/4.0$ . . . . .	210
25.4	Catadioptric Telescope, 1200 mm, $f/8.0$ . . . . .	212
<b>26</b>	<b>Zoom Lenses</b>	<b>215</b>
<b>Part D Special-Purpose Optics</b>		<b>223</b>
<b>27</b>	<b>Astrocameras</b>	<b>225</b>
27.1	Schmidt Camera . . . . .	225
27.2	Wright Camera . . . . .	229
27.3	Wynne Camera . . . . .	231
<b>28</b>	<b>Telecentric Machine-Vision Metrology Lens</b>	<b>235</b>
<b>29</b>	<b>Ultraviolet and Infrared Lenses</b>	<b>239</b>
29.1	Ultraviolet Celor Lens . . . . .	239
29.2	Mid-Wave Infrared Petzval Lens . . . . .	241
29.3	Mid-Wave Infrared Double-Gauss Lens . . . . .	244
29.4	Mid-Wave Infrared Hologon Lens . . . . .	244
29.5	Long-Wave Infrared Double-Gauss Lens . . . . .	247
<b>30</b>	<b>Widescreen Movie Systems</b>	<b>249</b>
30.1	Anamorphic Afocal Attachment . . . . .	250
30.2	360-Scope . . . . .	252
<b>31</b>	<b>The Mars Rover Camera Lenses</b>	<b>255</b>
31.1	The Cameras . . . . .	256
31.2	PanCams . . . . .	256
31.3	NavCams . . . . .	258
31.4	HazCams . . . . .	260
31.5	Microscopic Imager . . . . .	260
31.6	SunCam and Descent Camera . . . . .	264
31.7	Acknowledgments . . . . .	265
31.8	For Further Reading . . . . .	266
<b>Part E Timeline of Advances and Milestones</b>		<b>267</b>
<b>Appendix Optical Prescriptions</b>		<b>277</b>
<b>Index</b>		<b>305</b>

## Part A Concepts and Techniques

as much as the fore-and-aft departure of the sagittal surface. These three surfaces are illustrated in Figs. 8.4(a) and 8.4(b). Astigmatism can therefore be used to artificially flatten the field in some systems that unavoidably have a sizable Petzval sum. Examples are the Landscape lens, the Rapid Rectilinear lens, and most eyepieces.

### 8.3 Effective Focal Length and Back Focal Length

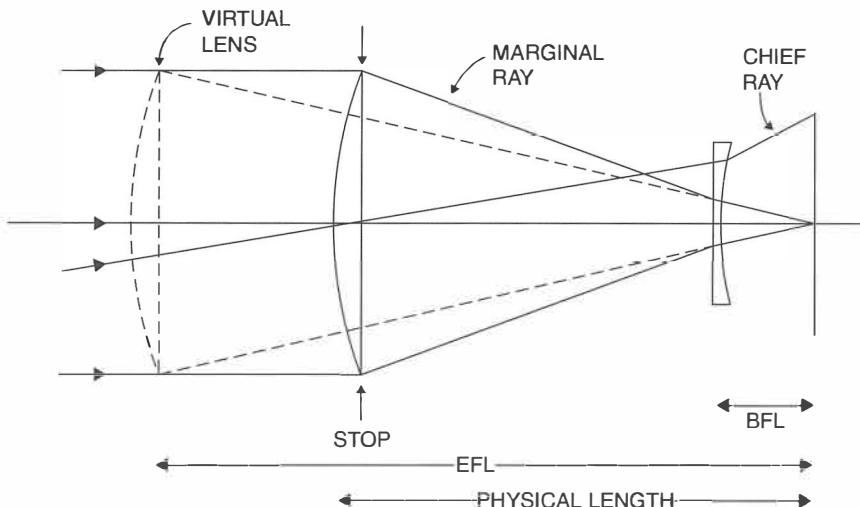
Two lens parameters of crucial importance are the effective focal length and the back focal length. The back focal length (or simply the back-focus) is the rear clearance between the lens and the image.

The effective focal length (EFL) determines the image scale, or how big the image is. The back focal length (BFL) determines where the image is located relative to the mechanical lens.

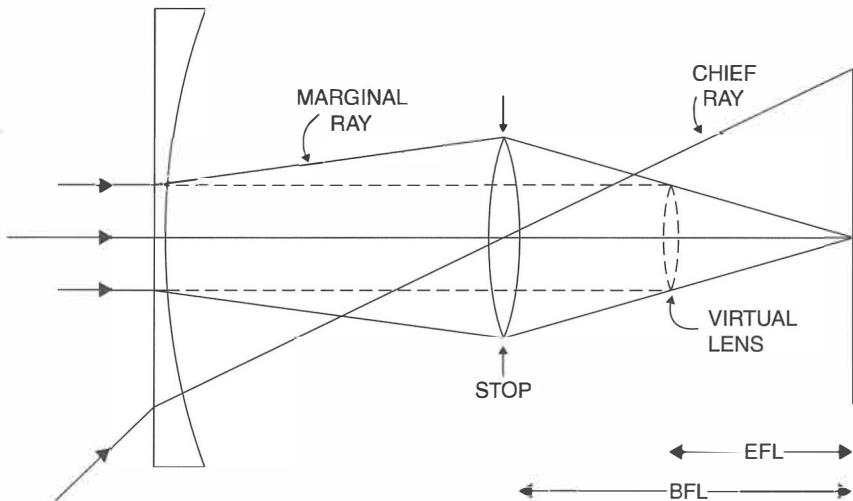
To illustrate the concepts of effective focal length and back focal length, consider the telephoto and retrofocus lens types.

Contrary to much popular usage, a telephoto lens is not merely a lens having a relatively long focal length and narrow field of view. A true telephoto lens has negative power in its rear section to create a more compact and convenient system whose physical length is shorter than its EFL. This unsymmetrical configuration is shown in Fig. 8.5. Note that the rear negative element causes the chief ray to increase its outward divergence, thus increasing image size. Astronomers use this same telephoto principle when they add a negative Barlow lens in front of focus to increase the focal length of their telescopes.

Conversely, a retrofocus lens (originally a trade name by Angénieux) is a backwards telephoto with negative power in front to create a system whose BFL



**Figure 8.5** Telephoto lens. From *Practical Computer-Aided Lens Design* published by Willmann-Bell, Inc. ([www.willbell.com](http://www.willbell.com)) Used with permission.



**Figure 8.6** Retrofocus lens. From *Practical Computer-Aided Lens Design* published by Willmann-Bell, Inc. ([www.willbell.com](http://www.willbell.com)) Used with permission.

is greater than its EFL. This unsymmetrical configuration is shown in Fig. 8.6. The retrofocus principle is most often used in wide-angle lenses that must provide extra clearance for a single-lens-reflex mirror. Retrofocus lenses are big and bulky for their focal length, but because wide-angle lenses have short focal lengths, this relatively large size is still practical. Note in Fig. 8.6 that the front negative element reduces the chief ray angle both inside the lens and on the image, thus allowing the rear part of the wide-angle lens to work with an effectively narrower field of view.

## 8.4 Aberrations in Terms of BFL and EFL

For a lens and a distant object, much insight can be gained about the basic seven aberrations by analyzing how BFL and EFL change (1) with wavelength, (2) with pupil zone height, and (3) with field zone height.

For BFL:

A change in BFL with wavelength causes longitudinal chromatic aberration,  
 A change in BFL with pupil zone causes spherical aberration, and  
 A change in BFL with field zone causes astigmatism and field curvature, that is, tangential and sagittal field curvature.

Similarly for EFL:

A change in EFL with wavelength causes lateral chromatic aberration,  
 A change in EFL with pupil zone causes coma, and  
 A change in EFL with field zone causes distortion.

# Chapter 21

## Wide-Angle Lenses

---

So far we have looked at standard or normal lenses for large-format cameras. A normal lens has a focal length roughly equal to the length of the film format diagonal. For  $4 \times 5$  film, this is 162.6 mm, or 150 mm when rounded. Pictures made with normal lenses have a perspective that is normal-looking to most people. However, for many types of subject matter, a wider field of view is required, and for this you need a wide-angle lens having a shorter focal length. Wide-angle lenses are very popular for use on large-format view cameras and field cameras. They are almost as popular as normal lenses.

### 21.1 Hypergon

In 1900, Emil von Höegh at Goerz (the same man who designed the Dagor) designed what is still perhaps the ultimate in wide-angle camera lenses. It was called the Hypergon, an appropriate name. On a flat photographic plate or film, it could image without distortion a huge object field about 136 ( $\pm 68$ ) degrees wide. Figure 21.1(a) is the layout of a Hypergon lens itself. Figure 21.1(b) is a similar layout but with the image surface included to show the extreme ray angles.

The Hypergon consists of two extreme-meniscus singlet lenses placed symmetrically about a central stop. There is no attempt to correct the longitudinal chromatic aberration or spherical aberration, so the lens must be used at a slow *f*-number. In the present case, maximum opening is *f*/16. The lens in this example is also designed for a different format than earlier examples. It is intended for use with an  $8 \times 10$  film and to form a round image area about 190 mm in diameter covering most of the middle of the picture. Focal length is 40 mm, and the object is at infinity.

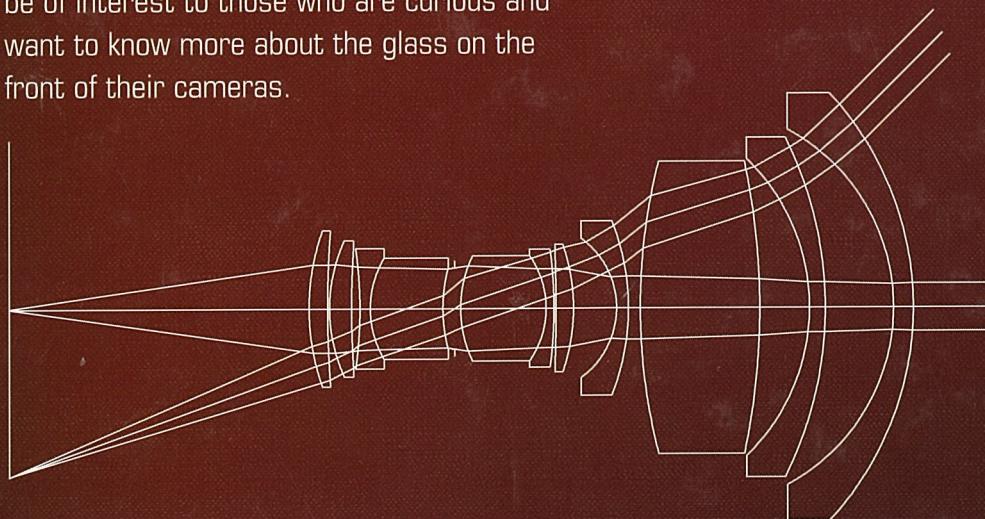
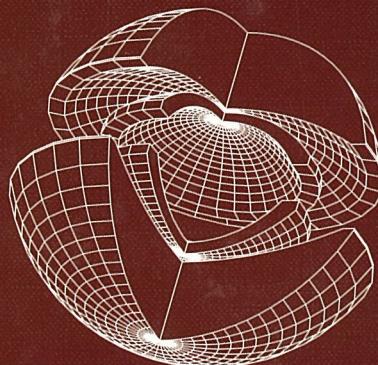
Figure 21.1(c) is the spot diagram for 0, 0.5, 0.8, and 1.0 of the  $\pm 68$  degree field. It has been evaluated using the five panchromatic wavelengths, 0.420, 0.450, 0.500, 0.570, and 0.660  $\mu\text{m}$ , all weighted equally. The spots are quite small, even without chromatic or spherical correction. The main aberrations on-axis are the remaining chromatic and spherical aberrations as balanced by some paraxial defocus (refocus). Off-axis, these aberrations are augmented by some lateral color and oblique spherical. All across the field, distortion is vanishing small; at the edge of the field, it is just +0.13%.

# Camera Lenses

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This book is an exploration and appreciation of cameras and their optics, covering all major lens types from the earliest to the most recent—including those roving the surface of Mars. A recurrent theme of this book is that lens types invented in the 19th century are just as useful in the 21st century. Another continuing theme is the impact of the digital revolution and the use of imaging in radically new circumstances. This book should be of interest to those who are curious and want to know more about the glass on the front of their cameras.



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